Journal of Food Engineering 121 (2014) 9–14

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Texture profile and correlation between sensory and instrumental analyses on extruded snacks

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ARTICLE INFO

Article history:
Received 27 March 2013
Received in revised form 26 July 2013
Accepted 5 August 2013
Available online 12 August 2013

Keywords:
Snack food
Texture
Instrumental analysis
Descriptive analysis

ABSTRACT

Instrumental texture analysis on extruded snacks is widely applied, however there is no scientific consensus about the test and probe types that can be correlated with the sensory texture of snacks. Eleven commercial extruded snacks of different shapes were evaluated instrumentally using different probes and sensorially through descriptive analysis. The snack texture was described using the attributes of hardness, crispness, adhesiveness, fracturability and chewiness. Cylindrical snacks were described through crispness and fracturability, pelleted and shell-shaped snacks by chewiness and ring-shaped snacks by adhesiveness and hardness. Hardness and adhesiveness were correlated with a Warner–Bratzler test using a "V" shape probe ($r = 0.718$ and $r = 0.763$, respectively), while fracturability and chewiness were correlated with a Warner–Bratzler test using a guillotine ($r = 0.776$ and $r = 0.662$, respectively). The fairly strong good correlations enable application of these instrumental tests as an indication of the sensory texture of extruded snacks.

1. Introduction

Texture, defined as the sensory manifestation of food structure and the way in which this structure reacts to the forces applied, represents the junction of all the mechanical, geometric and superficial attributes of a product, sensed through mechanical, tactile, visual and hearing receptors (Szczesniak, 1963a). Moreover, texture can be related to the deformation, disintegration and flow of the food when a force is applied (Bourne, 2002).

Texture can be measured by means of objective (instrumental) and intrinsic subjective (sensory) tests. Among the instrumental test devices, texturometers imitate mastication conditions and present excellent correlations with sensory evaluations of texture (Szczesniak, 1963b). For this reason, they have been widely used to measure the texture of different kinds of foods. With regard to sensory analysis in the mouth, the characteristics perceived include mechanical attributes (relating to reaction to the applied force), geometrical attributes (relating to the shape, size and particle orientation inside the food) and attributes relating to perception of moisture or fat content (Szczesniak, 2002).

Correlations between sensory and instrumental measurements of texture result in: (1) finding instruments to measure quality control of food in industries; (2) predicting consumer response, as the degree of liking and the overall acceptance of a new product; (3) understanding what is being sensed and perceived in the mouth during the sensory assessment of texture; (4) improving or optimizing instrumental methods to complementary the sensory evaluation (Szczesniak, 1987).

Texture is a critical sensory attribute that can dominate the quality of a product, as in snacks obtained through thermoplastic extrusion. In extruded snacks, expansion is desired and puffed products are expected, and this is why texture plays an important role regarding the acceptability of snacks among consumers (Anton and Luciano, 2007).

Many studies have measured the texture of snack products using instrumental analysis, but different tests and probes have been used. The tests most often applied have been texture profile analysis (Liu et al., 2000; Veronica et al., 2006), cut or shear tests (Conti-Silva et al., 2012; Saeleaw et al., 2012 and Yuliani et al., 2006), compression tests (Nath et al., 2012) and puncture tests (Ding et al., 2006; Pamies et al., 2000 and Nascimento et al., 2012). Besides the diversity of tests and probes applied, different sensory terms have been used to describe the texture diagnosed through the instrumental test, even when the same test and probe have been used. In other words, there is no consensus regarding which terms should be used to describe textures diagnosed through instrumental tests, or whether these terms can be correlated with sensory texture, although the terms most used are hardness, brittleness, firmness and crispness (Ding et al., 2006; Mazumder et al., 2007; Nascimento et al., 2012; Nath et al., 2012; Veronica et al., 2006; Yuliani et al., 2006).

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http://dx.doi.org/10.1016/j.jfoodeng.2013.08.007

Instrumental and sensory evaluations on snack textures have been widely performed, but it is important to establish which tests and probes are more appropriate for describing the sensory attributes of texture, thereby ascertaining which objective test correlates best with the sensory perception of texture. Therefore, the aim of this study was to evaluate the texture profile of extruded snacks and determine the most appropriate instrumental test for correlations with sensory analyses on snack texture.

2. Material and methods

2.1. Material

Four different shapes of extruded snacks were purchased in a local supermarket. The shapes were selected based on the most common types of snacks available on the market, which are cylindrical (Fig. 1A), pelleted (Fig. 1B), ring-shaped (Fig. 1C) and shell-shaped (Fig. 1D). Out of the eleven snack products purchased, three were cylindrical, three pelleted, two ring-shaped and three shell-shaped.

All cylindrical, ring-shaped and shell shaped snacks are made with corn flour, while pelleted snacks are made with wheat flour. Different raw materials to produce the snacks and different shapes were chosen precisely to involve a major variety of extruded snacks in this study.

2.2. Descriptive analysis of texture

Panelists were recruited from among the students, staff and professors of the Instituto de Biociências, Letras e Ciências Exatas, Universidade Estadual Paulista "Júlio de Mesquita Filho" (IBILCE). Descriptive analysis of texture was performed in accordance with Stone and Sidel (1993).

Twelve panelists out of the twenty recruited were preselected using a difference-from-control test relating to crispness. The three cylindrical snacks, among which one of them was standardized as a control sample based on the instrumental analysis, were subjected to the difference-from-control test. The panelists were preselected according to their discriminative capacity ($F_{sample} \leqslant 0.50$) and reproducibility capacity ($F_{repetition} \geqslant 0.05$) (ASTM, 1981).

The sensory attributes were generated by the twelve panelists, using the Kelly Repertory Grid method (Moskowitz, 1983) to describe the texture of the same three cylindrical snacks. After discussions to reach a consensus, the descriptive terms that were most important for characterizing the snack texture were selected. The sensory panel also defined the attributes, the references for each of these and the product evaluation form. During this stage, which took three sessions of 1 h each one, four panelists dropped out of the analysis, and thus, eight remained.

After the training stage with the same three cylindrical snacks, which took four sessions of 1 h each one, the panelists were selected according to their discriminative capacity ($F_{sample} \leqslant 0.50$), reproducibility capacity ($F_{repetition} \geqslant 0.05$) and capacity for consensus with the panel for each attribute (ASTM, 1981; Damásio and Costell, 1991). Thus, six of the eight trained panelist were selected to conduct analyses on the sensory texture profile of the snacks.

The sensory analysis was performed in individual booths, under red light and at a temperature of 22 °C. The eleven snacks were presented in plastic cups coded with three-digit random numbers and were evaluated in triplicate by the six panelists. The sample presentation was balanced with complete sets (performed in two sessions), that were randomized and monadic, and an unstructured linear intensity scale of 90 mm in length was used for each descriptor.

The ethical issues of the sensory analysis were approved by the Research Ethics Committee of the IBILCE.

2.3. Instrumental analyses of texture

The extruded snacks were analyzed by means of the TAXT2i texturometer (Stable Micro Systems, Godalming, UK), using a load cell of 5.0 kg and the following tests and probes:

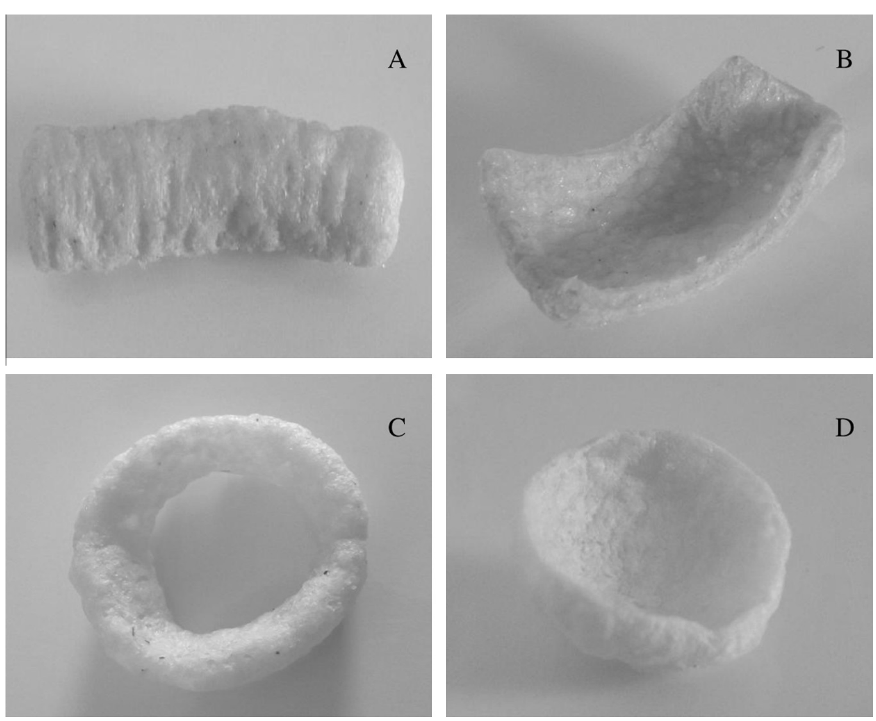

Fig. 1. Shapes of the extruded snacks. Legend: A (cylindrical), B (pelleted), C (ring-shaped) and D (shell-shaped).

– *Compression test*: an aluminum cylinder probe (Fig. 2A) was used, with diameter 25 mm, test speed of 1 mm/s and compression of 50% of the sample height. The necessary force to compress 50% of the sample height, in newtons, was taken to be the result from the test.
– *Cut test*: a Warner–Bratzler shear blade with guillotine probe (Fig. 2B) was used, with test speed of 1 mm/s. The cut was performed perpendicularly to the main axis of the snack until completely breaking it. The peak force obtained, in newtons, was taken to be the result from the test.
– *Cut test*: a Warner–Bratzler shear blade with a "V" shape probe (Fig. 2C) was used, with test speed of 1 mm/s. The cut was performed perpendicularly to the main axis of the snack until completely breaking it. The peak force obtained, in newtons, was taken to be the result from the test.
– *Puncture test*: a needle probe (Fig. 2D) was used, with test speed of 1 mm/s and perforation of 50 % of the sample thickness. The peak force obtained, in newtons, was taken to be the result from the test.
– *Shear test*: a Kramer shear cell five-blade probe (Fig. 2E) was used, with test speed of 1 mm/s. Sufficient quantity of snack was used to cover the bottom of the cell, without overlapping of the pieces, and shearing was performed until the probe had completed its travel. The peak force obtained, in newtons, was taken to be the result from the test.

Before the analyses, the snacks were carefully cut to achieve standardization regarding the shape for the instrumental test:

– *Compression test*: all snacks were cut into squares of side length 1.5 cm (smaller than the probe);
– *Cut test with guillotine, cut test with "V" shape probe and puncture test*: the cylindrical and ring-shaped snacks were standardized with lengths of 3 cm; the pellet snacks were cut into rectangles of length 2 cm and width 1.5 cm; the shell-shaped snacks were cut to have a diameter of 1.5 cm.
– *Shear test*: the original shape of all the snacks was preserved.

All analyses were performed at ten replicates.

2.4. Statistical analysis

The means of the sensory attributes were compared using variance analysis followed by the Tukey test (significant difference

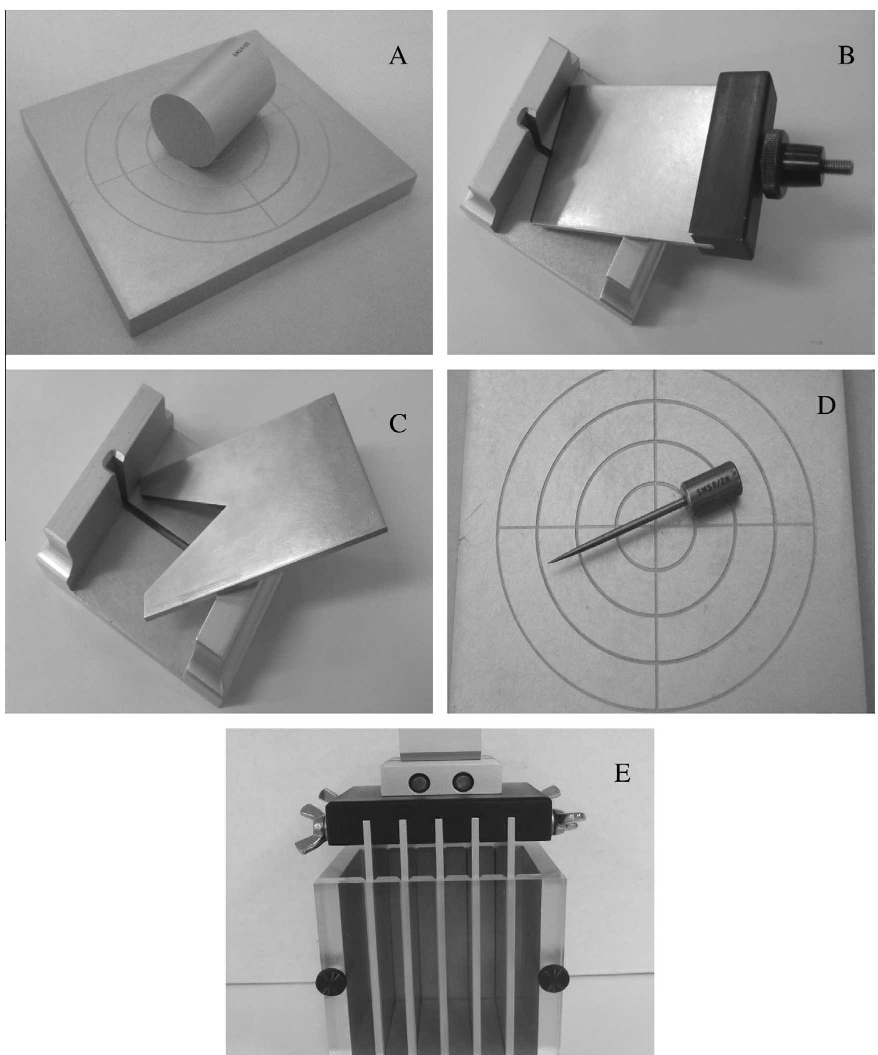

Fig. 2. Texturometer probes. Legend: A (aluminum cylinder probe with diameter of 25 mm), B (Warner–Bratzler shear blade with guillotine probe), C (Warner–Bratzler shear blade with "V" shape probe), D (needle probe) and E (Kramer shear cell five-blade probe).

when $p \leqslant 0.05$), using the PASW Statistics 18 software (SPSS Inc.), since all of the data follow a Gaussian distribution. The results were also standardized and subjected to cluster analysis followed by multidimensional scaling analysis, using the Statistica 7.0 software (StatSoft, Inc.).

The texture means obtained by instrumental tests were compared using variance analysis followed by the Tukey test (significant difference when $p \leqslant 0.05$), using the PASW Statistics 18 software (SPSS Inc.), since all of the data follow a Gaussian distribution.

Pearson correlation analysis was performed between the eleven means of the five sensory attributes of texture and of the five instrumental tests, using the PASW Statistics 18 software (SPSS Inc.), because the means follow a Gaussian distribution. In addition, the same means from the sensory and instrumental analyses were subjected to Principal Component Analysis (PCA), using the Statistica 7.0 software (StatSoft, Inc.). For PCA analysis, the sensory attributes and instrumental tests were fixed in columns (variables) and the snacks in lines (cases), and the data were standardized before analysis. The PCA analysis was performed with correlation matrix and without factor rotation.

3. Results and discussion

3.1. Descriptive analysis on texture

The texture of the snacks was described using the attributes of hardness, crispness, adhesiveness, fracturability and chewiness (Table 1). These are the most used descriptors in studies evaluating the texture of extruded snacks (Ding et al., 2006; Liu et al., 2000; Nascimento et al., 2012; Nath et al., 2012; Veronica et al., 2006; Yuliani et al., 2006). Furthermore, while hardness relates to the "force applied by the molar teeth to compress the food", fracturability relates to the "ability to break food into pieces when it is bitten using the incisors". Thus, different forces applied by the teeth were evaluated. A similar investigation was conducted by Varela et al. (2009) to evaluate the crispness of extruded snacks.

The hardness, crispness, adhesiveness and fracturability of the snacks were discriminated by the panelists, while only chewiness was not different for all the samples (Table 2). In general, cylindrical snacks presented higher degrees of hardness, adhesiveness and fracturability than shown by other shapes.

Cluster analysis showed three groups of sensory attributes (Fig. 3A): one group for hardness and adhesiveness and another group for the attributes of crispness and fracturability, while chewiness was kept in a separate group. Groups are formed based on Euclidean distances, which means that values of hardness and adhesiveness and of crispness and fracturability are proximal between them, while values to chewiness is more distant from the others attributes.

Multidimensional scaling (Fig. 3B) was used to present the spatial dispersion of the snacks in relation to the sensory attributes of texture. This could be evaluated using the stress value, which indicated the goodness-of-fit of the model. Stress values below 0.01 indicate that the data conform to the model, i.e. the model fits well (Johnson and Wichern, 1992; Kruskal and Wish, 1978). The stress value, in this case, was 0.0000.

Cylindrical snacks were described in terms of crispness and fracturability, while ring-shaped snacks were described by adhesiveness and hardness. Although chewiness was not discriminated by panelists (Table 2), the multidimensional scaling showed that shell-shaped and pelleted snacks were described by the chewiness.

3.2. Instrumental texture

The different probes and tests applied resulted in different mean forces and, as in the sensory analysis, the snacks were discriminated according to the type of instrumental test (Table 3). In general, cylindrical snacks showed higher forces when the cut tests were applied, while shell-shaped snacks presented higher forces when the puncture test was used. The values found in the present study were lower than what was found for different kinds of extruded snacks in the literature, comparing similar tests and probes (Conti-Silva et al., 2012; Ding et al., 2006; Veronica et al., 2006), although some studies have shown similar results (Nath et al., 2012; Pamies et al., 2000) or lower values compared to the present study (Liu et al., 2000; Saeleaw et al., 2012).

3.3. Correlation between sensory and instrumental texture

The instrumental forces derived from the cut tests were correlated with the sensory attributes of texture (Table 4). Hardness correlated positively with both cut tests, although the correlation coefficient for the cut test with a "V" shape probe ($r = 0.718$) was higher than for the cut test with a guillotine ($r = 0.687$). The adhesiveness of the snacks correlated positively with the cut test using a "V" shape probe ($r = 0.763$) and chewiness correlated positively with the cut test with a guillotine, although the correlation coefficient was only 0.662. Similarly to hardness, fracturability correlated positively with both cut tests, although the correlation coefficient was higher for the cut test with a guillotine (0.776). Correlation coefficient about of 0.70 indicates fairly strong correlation according to Rayner (1969) cited by Leighton et al. (2010). No significant correlation was found with crispness.

Varela et al. (2009) evaluated the crispness of two types of extruded snacks (wheat crusts and cheese balls) by means of compression and puncture tests and by using a sensory panel, who bit the snacks with the incisor teeth and chewed them with the back molars. These authors reported that the ratings from the biting and chewing tests were very similar and that the results obtained from the sensory evaluation were similar to the instrumental results, although no correlation analysis was performed.

Table 1
Definitions and references for sensory attributes of the extruded snacks.

Sensory attribute	Definition	References
Hardness	Force applied by the molar teeth to compress the food	Low: Finger-sized soft bread rolls (Pullman) High: Hard candy (Halls)
Crispness	Noise of food during mastication	Low: Finger-sized soft bread rolls (Pullman) High: Breakfast cereal (Crunch)
Adhesiveness	Ability of food to adhere to the teeth when chewed	Low: Sliced carrot with thickness 2 mm High: Toffee candy with caramelized milk sweet (Arcor)
Fracturability	Ability to break food into pieces when it is bitten using the incisors	Low: Sliced carrot with thickness 2 mm High: Commercial toast (Pullman)
Chewiness	Number of chews necessary for food to be swallowed	– –

Table 2
Intensity of the sensory attributes for the extruded snacks (mean data ± SD, $n = 18$).

Snacks	Hardness	Crispness	Adhesiveness	Fracturability	Chewiness
Cylindrical 1	4.2 (2.2)[b]	6.6 (1.8)[b]	4.6 (2.2)[abc]	6.7 (1.0)[d]	11.3 (4.9)[a]
Cylindrical 2	3.2 (2.2)[ab]	6.1 (1.5)[b]	4.7 (2.2)[bc]	6.0 (1.5)[cd]	10.9 (5.1)[a]
Cylindrical 3	3.2 (2.2)[ab]	6.0 (1.5)[ab]	4.9 (1.7)[c]	5.7 (1.3)[bcd]	10.3 (4.3)[a]
Pelleted 1	3.4 (1.9)[ab]	4.8 (2.1)[ab]	2.9 (1.6)[ab]	4.5 (1.8)[ab]	10.7 (5.2)[a]
Pelleted 2	2.3 (1.4)[ab]	5.7 (2.3)[ab]	2.7 (1.8)[ab]	4.1 (1.5)[a]	9.5 (4.2)[a]
Pelleted 3	1.8 (0.9)[a]	6.0 (2.3)[ab]	2.6 (1.5)[a]	4.2 (1.5)[ab]	8.6 (3.5)[a]
Ring 1	2.8 (1.6)[ab]	6.3 (1.6)[b]	3.8 (1.9)[abc]	5.2 (1.7)[abcd]	11.2 (5.4)[a]
Ring 2	3.0 (1.6)[ab]	6.6 (1.5)[b]	3.5 (1.7)[abc]	6.2 (1.1)[cd]	12.2 (6.9)[a]
Shell 1	3.1 (1.8)[ab]	6.3 (1.5)[b]	3.7 (2.1)[abc]	5.7 (1.4)[bcd]	8.7 (3.8)[a]
Shell 2	2.3 (1.1)[ab]	4.1 (2.0)[a]	3.5 (1.9)[abc]	3.7 (1.3)[a]	8.8 (4.0)[a]
Shell 3	2.6 (1.4)[ab]	5.3 (1.7)[ab]	3.9 (1.9)[abc]	5.1 (1.3)[abc]	9.3 (4.4)[a]

Different letters in the same column indicate different means ($p \leqslant 0.05$).

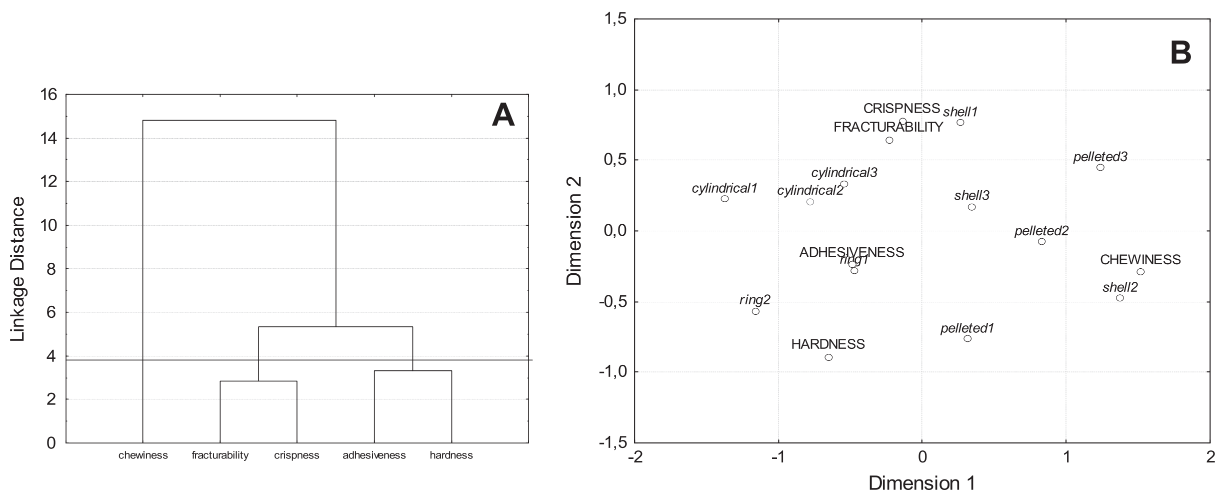

Fig. 3. Euclidean distances diagram (A) and multidimensional scaling (B) on sensory texture of the extruded snacks.

Table 3
Instrumental texture measurements[a] for the extruded snacks (mean data ± SD, $n = 10$).

Snacks	Compression force	Peak of cut-guillotine	Peak of cut-"V" shape	Peak of puncture	Peak of shear
Cylindrical 1	33.4 (5.8)bcd	19.9 (3.1)[d]	26.2 (2.6)[f]	5.2 (0.6)[ab]	185 (24.4)[bc]
Cylindrical 2	34.2 (5.1)[bcd]	18.4 (2.4)[cd]	21.2 (2.1)[e]	5.4 (0.8)[ab]	250 (23.4)[d]
Cylindrical 3	21.6 (4.1)[ab]	12.6 (0.8)[abc]	16.3 (1.9)[cd]	3.7 (0.5)[a]	188 (19.9)[bc]
Pelleted 1	22.3 (4.7)[ab]	13.3 (5.3)[abc]	12.3 (2.5)[bc]	7.3 (1.9)[bc]	186 (17.8)[bc]
Pelleted 2	26.3 (9.6)[abc]	13.2 (6.8)[abc]	12.3 (3.1)[bc]	7.6 (3.0)[bc]	164 (22.0)[b]
Pelleted 3	13.0 (3.0)[a]	11.3 (1.6)[a]	6.8 (0.8)[a]	5.3 (0.7)[ab]	100 (10.8)[a]
Ring 1	13.8 (2.0)[a]	12.4 (6.1)[ab]	12.7 (3.4)[bc]	6.7 (1.4)[ab]	178 (24.4)[bc]
Ring 2	37.6 (8.5)[cd]	18.1 (4.6)[bcd]	13.7 (1.6)[bc]	8.0 (2.1)[bc]	113 (22.3)[a]
Shell 1	28.8 (11.9)[bc]	13.5 (2.9)[abc]	11.7 (3.8)[b]	10.2 (2.3)[cd]	295 (30.7)[e]
Shell 2	45.7 (22.9)[d]	12.6 (2.6)[abc]	14.9 (2.9)[bcd]	12.8 (5.4)[d]	301 (17.8)[e]
Shell 3	25.4 (10.9)[abc]	14.0 (3.7)[abcd]	18.5 (6.0)[de]	10.1 (1.6)[cd]	214 (48.8)[cd]

Different letters in the same column indicate different means ($p \leqslant 0.05$).
[a] All results are expressed in newtons (N).

Table 4
Coefficients of correlation between sensory and instrumental texture measurements for the extruded snacks.

	Hardness	Crispness	Adhesiveness	Fracturability	Chewiness
Compression	0.223	−0.237	0.243	0.138	0.111
Cut-guillotine	0.687*	0.478	0.484	0.776**	0.662*
Cut-"V" shape	0.718*	0.172	0.763**	0.640*	0.427
Puncture	−0.332	−0.574	−0.318	−0.442	−0.437
Shear	0.143	−0.406	0.365	−0.06	−0.369

* $p \leqslant 0.05$.
** $p \leqslant 0.01$.

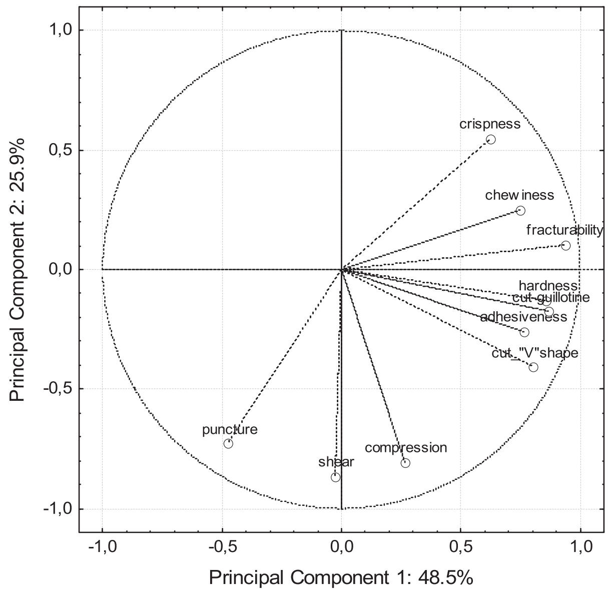

Fig. 4. Principal component analysis on sensory and instrumental texture of the extruded snacks.

Principal component analysis on the sensory and instrumental data (Fig. 4) showed that the first and second principal components explained, respectively, 48.5% and 25.9% of the observed variation (74.4% in total). The significance level of Bartlett's test of sphericity was 0.000, which indicates that the correlation matrix is not an identity matrix and that principal component analysis can be applied to the data (Hair et al., 1998).

All sensory attributes (hardness, crispness, adhesiveness, fracturability and chewiness) and the instrumental forces with a guillotine and with a "V" shape contributed to explain the variance of principal component 1, while compression, puncture and shear tests explained the variance of principal component 2. These results show that instrumental forces derived from the cut tests present stronger correlation with sensory attributes, as seen in Table 4.

Also notice that puncture test, as seen in Table 4, is negatively correlated with sensory attributes, because it is positioned in the quadrant opposite to them.

4. Conclusions

Cylindrical snacks are described by crispness and fracturability, while ring-shaped snacks are described by adhesiveness and hardness, and chewiness is important to describe shell-shaped and pelleted snacks. The instrumental forces derived from the cut tests correlate strongly with sensory attributes, and that hardness and adhesiveness present correlations with the Warner–Bratzler test using a "V" shape probe, while fracturability and chewiness correlate with the Warner–Bratzler test using a guillotine. The fairly strong good correlations enable application of these instrumental tests as an indicator of the sensory texture of extruded snacks, which facilitates comparisons among scientific works and allows to industries produce extruded snacks with desirable sensory texture characteristics.

Acknowledgement

The authors are grateful for financial support from FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) (Grant 2011/08492-4).

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